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Specifications for optical gratings

By ERIK INGELSTAM[1]

With 3 plates

The following scheme has been worked out on behalf of the International Commission of Optics to serve as guidance for purchasers and users of gratings.

A. Standard of dimensions, material etc.

1. Materials

Common materials for blanks are:

a. Aluminum on chromium on glass
b. Gold on glass
c. Glass
d. Speculum metal

Thermal expansion coefficients: for a, b and c ordinary glasses $9 \cdot 10^{-6}$, Pyrex glass $3.6 \cdot 10^{-6}$, for d speculum metal $18.6 \cdot 10^{-6}$.

2. Ruled areas

Blanks are usually circular, although rectangular and octagonal blanks are sometimes used. In particular, large blanks are often rectangular.

The width of the ruled area should be given, and also the length of the grooves when this is critical.

Usually the maximum width of rulings commensurate with the size of the blank is employed, and standard diameters for blanks are as follows,

50 mm
80 mm
100 mm
150 mm
200 mm
250 mm

Tolerance should be given when necessary.

The thickness of the blank must be at least 1/8 its largest dimension.

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3. Radius of curvature for concave gratings.

The following radii, which have been frequently employed, are suggested as standards,

1 metre
1.5 metres
2 metres
3 metres
6.4 metres (nearly 21 feet)
10 metres

The tolerance should be about ±2 per cent.

The aperture of the smaller gratings can be as high as 1 : 10 but should ordinarly be less.

4. Precision of surface form.

Concave gratings for common spectral analysis and other gratings of 2 metres focus or less should conform to a spherical shape to within a quarter of a wavelength of visible light. The manufacturer of the blank can easily test this by means of a corresponding convex test surface.

For research gratings the tolerance should be specified according to the purpose, also that for maximum angle of incidence when of importance. The tolerance ought not to exceed half the value of the minimum wavelength divided by the order of the spectrum.

The same qualities should apply to the planeness of a plane grating blank.

5. Values of the grating spaces.

From Appendix 2 containing a list of present manufacturers and new laboratories which are undertaking manufacture of gratings, it appears that spacings are available within the following limits, in some cases at fixed values, in other cases variable as desired. It is recommended to specify the spacing as done here in the first column:

Spacing in A (Ref. 1)	grooves/mm	grooves/inch
6940	1440	36,600
│	│	│
33,800	295	7500

or more for the infrared region.

6. Origin of the grating.

It is recommended that the ruler's name and date of ruling, possibly also a number, be signed on every grating obtained.

B. Test of quality of gratings

1. Periodic errors.

11. Rowland ghosts.

Test: Observe the mercury spectrum in all available orders with a narrow slit through an eyepiece. If ghosts are seen even feebly, a rough estimate of the intensity of the strongest ghosts relative to the main line should be made. As this relative intensity is ordinarily roughly proportional to the square of the order of the spectrum, the estimate is most easily made in higher orders, but the results should be reduced to first-order values by means of this square law. One of the following methods is recommended: 1) Take a series of exposures with different times and estimate the time ratios for obtaining the same density of ghost in one photograph and of main line in another. (Only rough results.) 2) A rhodium on glass step filter is arranged so that the steps cover the main line, and the ghost appears near the edge of the filter. Thus the main line can be seen through the filter while the ghost is unobscured. Judge by eye the step on which both lines appear to have the nearest to equal intensity. (Rapid and in most cases sufficiently accurate.) 3) Direct measurement with a photomultiplier tube known to respond linearily to intensity. The slit is moved, and peak values of main line and ghosts are measured. 4) A disc with a radial slit of adjustable width is rotated behind the main line to reduce its intensity in a known way; the ghost intensity is compared visually with this reduced intensity. (E. g. disc of 400 mm circumference, slit width adjustable to about 1 mm gives the order of 1/400).

Specification: *Rowland ghosts are not present with intensity larger than . . . per cent in the first order, or, Rowland ghosts are present with an intensity of approximately . . . per cent on the first order.*

12. Lyman ghosts.
Test: Visual observation with the mercury source and a wide slit of the region between the central image and the violet first order will in general reveal Lyman ghosts when they are present. The intensity used must be large enough to reveal Lyman ghosts more intense than 0.001 per cent of parent line. If necessary, the intensity of Lyman ghosts relative to the main lines should be determined. This is especially important for gratings to be used in the extreme ultraviolet.

Specification: *Lyman ghosts are not present with intensity larger than . . . per cent, or, Lyman ghosts are present with an intensity of approximately . . . per cent.*

2. Resolving power and line form.

21. Observed line form and knife-edge test. (Required only for research gratings.)
Test: With the grating in good adjustment and focus and using a narrow slit, observe the lines in the iron arc spectrum visually with an eyepiece, and note whether they are perfectly symmetrical (Ref. 2). If they are, continue as suggested under 22. If not, screen off the intense portion of the line, and observe visually or photographically the distribution of light across the grating to find the portions responsible for the wings or satellites. This can be done by the knife-edge test. Let a razor blade, mounted on a micrometer carriage, traverse an intense isolated line (best in the mercury spectrum), following the focal plane, and view the grating surface from behind without an eyepiece. In an ideal grating the light should vanish at the same time in the whole area; portions causing satellites or other irregularities will stand out bright. Mask these portions off until the line is satisfactory, if possible.

Specification: *Lines* $\frac{\textit{are}}{\textit{are not}}$ *symmetrical when the whole area is used. If not, widths and portions of the necessary masks should be stated.*

22. Target patterns.

Test: Expose a photographic plate about halfway between the grating and focal plane so that patterns for the individual mercury lines will be well separated.

Specification: Negative or print of target patterns are to be furnished. Does the pattern resemble that in Fig. 1, or that in Fig. 2 reproduced here? (Ref. 3).

23. Comparison with standard lines patterns.

In this respect, gratings are divided into three groups,

a. Gratings for common spectral analysis, and others of 2 metres focus or less.
b. Plane gratings for research, and concave gratings of 3 metres or more in radius of curvature, which have a resolving power of up to 100,000.
c. Ditto, with a resolving power in excess of 100,000.

Test for a: Photograph the iron arc spectrum in the blue, or near ultraviolet region. Compare with Fig. 3. (Ref. 4).

Specification: Original negative should be furnished, and notes could be given concerning resolving power founded on separation of certain doublets.

Test for b: The grating should be put into the best adjustement, and the slit should have the proper narrowness. A slit width of λ/ϕ, where ϕ is the aperture of the grating, is recommended as a standard value giving 80 % of the nominal resolving power. A vacuum or low pressure mercury lamp with low current density should be used as a light source (Ref. 5). Photograph at two different densities a hyperfine structure of a line chosen so as to reveal the resolving power expected from the data of the grating. For average research gratings the green mercury line 5461 A is recommended. In the case of a plane grating, the focal length of the lens should be 3 metres or more. Compare with fig. 4.

Specification: Original negatives should be furnished. Further data on resolving power founded on the separation of line structures should be given.

Test for c: Photograph the green or one of the other mercury lines (Ref. 5). Examples of suitable complex lines can be found in references (6) and (7). An alternative test is to register the intensity distribution of the line with a phototube or photomultiplier tube and a recorder. See Fig. 5 (Ref. 8). One of the severest tests on gratings of high resolving power can be made with the iodine vapor absorption spectrum at room temperature (Ref. 9). See Fig. 6.

Specification: Sample photograph, or intensity distribution curve, of hyperfine structure, should be supplied.

Alternative test for b and c (Ref. 10): Select a region of a spectrum containing isolated fine and symmetrical lines, e.g. in the iron arc spectrum (Ref. 2). Place a casette, which can be moved by a micrometer across the beam, in the focal plane. Make a series of exposures with the casette moved in measured steps. Determine the minimum step necessary for resolution, and state the result in wavelength units and resolving power. — To avoid the difficulties from photographic blackening factors it is preferable to register the lines electrically with linear response (photomultipliers). The separation of the spectrum in two components is performed by using a double light-source slit, one part movable towards the other by a micrometer (Ref. 10).

Specification: Give the experimental resolving power and notes of the line and step size used in this moving-spectrum method.

3. *Distribution of intensity with the angle*

This specification is of importance in common gratings and specially those of echelette character. While in older common gratings the distribution of intensity was often haphazard, modern gratings of medium and large spacings are often ruled so as to concentrate the light into special orders and directions. This is done by giving the ruling an echelette character; e. g. grooves made asymmetrical with one edge flat, which is possible by using a shaped ruling diamond. When the echelette character is very prominent, particular specifications on the angle of the groove's flat edge or on preferred directions of reflexions are recommended. From these specifications are totally excluded the echelle gratings recently proposed by Harrison (Journ. of the Opt. Soc. *39*, 522, 1949). Detailed specification is also necessary for gratings used in grazing incidence. These types excluded, information according to the following test is sufficient for most purposes; it is founded on the fact that the distribution of intensity is in general a function of the angle rather than of the wavelength and order.

Test: For a rough estimate, hold a narrow strip of white paper perpendicular to the surface of the grating, observe the relative intensity of the images reflected in different orders. If any marked concentration of light in particular orders is noticed, quantitative measurements should be made as follows. The grating is illuminated by the mercury lamp with a wide slit, and the relative intensities of all observable orders of the green line are measured by a photoelectric or barrier-layer cell a) with normal incidence, b, c) with 45° incidence on each side.

Specification (proposed):

	a) Normal incidence		b) 45° from left (top of grating to be specified)		c) 45° from right	
0. order..........	1.0		1.0		1.0	
	left	right	left	right	left	right
1. order..........	....	....	....	....	....	....
2. order..........	....	....	....	....	....	....
3. order..........	....	....	....	....	....	....
....	....	....	....	....	....	....

4. *Common stray light*

This test is to classify gratings with respect to scattering properties. For special use or with special mountings, for example in the ultraviolet region, further studies are of value (Ref. 12). Concerning the type of stray light adjacent to a spectral line at its foot, see reference (11).

Test: Illuminate the grating at normal incidence by a continuous spectrum, for instance from a tungsten band lamp, the ultraviolet part being absorbed by a filter. Near the source insert a dense didymium filter whose spectral transmission is known or measured. With a photomultiplier tube having a broad spectral response curve in the visible region, measure the intensity in the absorption band at 5800 A with and without the didymium plate. Compare and calculate from known spectral curves the ratio of stray light to adjacent continuous spectrum when the incoming spectrum is that of tungsten of about 2800° K color temperature (Ref. 12).

Spezification: Common stray light is not in excess of . . . per cent of adjacent continuous spectrum.

Appendix 1. References

1) A, which in European text is commonly written Å, represents the international Angstrom founded on the line standards, not the original Angstrom.
2) Sufficiently symmetrical lines of the iron arc spectrum are given in St. John and Babcock, Astrophysical Journal *42*, 231, 1915; *46*, 138, 1917, and 53, 260, 1921. For gratings of lower resolving power proper lines can be chosen from an atlas, e.g. in Ref. (4).
3) Reproduced from an article by Harrison, Proc. Seventh Summer Conference on Spectroscopy p. 58 (Wiley & Sons, New York 1940). Also reproduced in Harrison, Lord and Loofbourow, Practical Spectroscopy (Prentice Hall, New York 1948).
4) Registered with a prism spectrograph. From Gatterer and Junkes, Arc Spectrum of Iron from 8388 to 2242 A. (Specola Vaticana, Città del Vaticano 1947).
5) E. g. a Cooper-Hewitt vacuum mercury lamp, current density not more than some 0.5 amps/cm^2, or a Geissler tube with the same low current density.
6) Schüler and Keyston, ZS. f. Phys. *72*, 423, 1931.
7) Schüler and Jones, ZS. f. Phys. *74*, 639, 1932, and *77*, 801, 1932.
8) By courtesy of Mr B. Kleman, Stockholm University Physics Laboratory.
9) According to a communication from H. D. Babcock. He writes: "The method is best applied with sunlight. Among the thousands of these iodine lines in the green-yellow, all of which are extremely narrow, are found many examples of pairs and triplets which can be resolved only with high power. Others are suitable for resolving powers of around 100,000." Fig. 6 shows a small part of the green region of the solar spectrum with an iodine tube at room temperature in the beam of light.
10) Hulthén and Uhler, Arkiv för fysik, to appear.
11) Jacquinot, Colloque sur la théorie des images optiques, p. 183, Editions de la Revue d'Optique, Paris 1949.
12) Ingelstam and Djurle, Arkiv för fysik, to appear.

Appendix 2. List of manufacturers

The list below is the result of inquiries directed to institutes which are known to rule gratings or to be preparing new arrangements for ruling gratings. The notes are founded on information given by the institutes themselves, although they have been rearranged and abbreviated in some cases for the sake of uniformity. The author has tried to supply data of spacings and maximum ruling areas (length of grooves × width of area) necessary for users of gratings. The list may not be complete concerning small and simple gratings, as there are other manufacturers of gratings up to 50 mm in the U. S. A. The cheap transmission replicas for simple monochromators and educational use have been omitted.

Attention may be called to an article by Harrison, Journ. of the Optical Society *39*, 413 (June number) 1949, in which many interesting notes and views on the ruling of gratings are given.

1. Applied Research Laboratories, 4336 San Fernando Road, Glendale 4, California, U. S. A.

The firm produces gratings only for use in their own spectrographs or as substitutes for such. Radius of curvature: 1.5 and 2.0 metres. Spacings 10,420 A and 6,940 A, ruled areas 25 × 51 mm and 32 × 63 mm. Ruled on speculum metal, after ruling coated with aluminum. Rowland ghosts are kept to less than 0.2 per cent of the parent line, Lyman ghosts less than 0.1 per cent.

2. Baird Associates, Inc., 33 University Road, Cambridge 38, Massachusetts, U. S. A.

The present production consists almost exclusively of concave gratings radius of curvature 3 metres, spacing 16,900 A (15,000 grooves/inch), in aluminum on chromium on glass, on pyrex blank 100 mm in diameter. They are for the most part reserved for use in their own instruments. The ruling machine for this purpose is in continuous production, a second one is being constructed, and a third engine is comtemplated. It is possible that within the course of the next few years the firm will supply a more general market.

3. Bausch & Lomb Optical Co., Rochester 2, New York, U. S. A.

This firm has installed and improved the Gale machine from the University of Chicago, and the quality of the rulings is improving steadily. It is intended to rule gratings of moderate size, up to 150 mm. Normal spacing of 16,700 A (600 grooves/mm), or less in ratios 2/3, 1/2, 1/3, 1/6 of it can be ruled. Groove form will be settled by means of diamond shaping. — The question as to whether gratings separate from instruments will be supplied has not yet been decided upon; primarily the production is planned for the manufacture of grating instruments.

The firm is also developing processes for making high class replicas.

4. Harrison, G. R., Massachusetts Institute of Technology, Cambridge 39, Massachusetts, U. S. A.

Dr. Harrison leads the work with rebuilding and improving the largest of the machines formerly at the University of Chicago now transformed to the MIT. This machine is designed to rule gratings up to about 400 mm size, with 350 × 250 mm ruled surface. The instrument will provide any desired spacing from about 8,500 A to about 50,000 A. Dr. Harrison reports of his plans: "Here at MIT we plan to do research work on gratings rather than production work, though if successful, we shall, of course, be glad to distribute any gratings we may produce where they will do the most good. We expect to make no commercial tie-up, but will sell gratings at approximately the cost of production to laboratories where they can be effectively used."

5. Jarrell-Ash Company, Boston, U. S. A.

Information has been given that an apparatus for ruling gratings is under construction. No further data have been given up till now.

6. Johns Hopkins University, Institute of Physics, Baltimore, Maryland, U. S. A. J. Strong is now in charge of the grating production.

There are three machines available, which as is well known have produced most of the large gratings in the world.

A. Rules ordinarily with a spacing of 16,900 A (15,000 grooves/inch).

B. Rules ordinarily with a spacing of 8,500 A (30,000 grooves/inch).

C. Is normally used for gratings that require less precision, such as gratings used in the infrared, and rules with spacings of 16,900 A, and multiples.

The standard surface is aluminum on glass. Experiments are going on with gold surfaces, afterwards aluminized, whence the aluminum could be removed and reapplied. Maximum size 200 mm diameter. With the spacing of 8,500 A good concentration could be attained in the first order visible and second order ultraviolet.

7. Mount Wilson and Palomar Observatory, Pasadena, California, U. S. A.

Two large machines are in operation, both adjustable to rule a variety of spacings. The spacings usually range between 8,000 A and 50,000 A, most commonly 16,700 A and 25,000 A. The smaller machine will rule an area 170 × 250 mm, the larger is designed for areas up to 450 × 500 mm but has not yet operated successfully on such areas. The standard surface is aluminized pyrex. Most of the rulings are made on plane surfaces (in combination with Schmidt cameras the advantages of the concave gratings are retained). The Institution (the ruling activity is lead by Dr. H. W. Babcock) is not organized to engage in commercial activities and has not accepted orders to produce gratings for sale. It is possible, that after a year or two completely devoted to the needs of the Observatories, some gratings could be produced for sale. The gratings are thus research ones, and accordingly designed for special purposes. Concentration and resolving power are accomodated to the purpose, the resolving power being close to the theoretical one.

8. The National Physical Laboratory, Teddington, Middlesex, Great Britain.

The exact status of the Blythswood machine after a pause in the ruling activity during 1948 is unknown. Earlier the machine had not been thoroughly revised since 1932. The definition on higher orders was reported to be somewhat defective. The spacing is 17,400 A (576 grooves/mm), the maximum area is 50 × 80 mm, the standard blanks 114.3 mm in diameter. Some coarser and larger gratings for the infrared region have been ruled.

9. The National Standards Laboratory, Sydney, Australia.

The machine originally constructed by Grayson is reported as being put into operation again.

10. The Perkin-Elmer Corporation, Glenbrook, Connecticut, U. S. A.

This firm collaborates with the Johns Hopkins University in making superior replicas and improving methods in this field.

11. Siegbahn, M., Nobel Institute of Physics, Stockholm 50, Sweden.

Two machines are in operation: one smaller and one larger. The small machine rules normally with a spacing of 17,400 A (576 grooves/mm), or, when demanded, with 8,700 A or multiples; maximum ruled area 50 × 80 mm. Resolving power is close to the theoretical value. — The large machine has recently been adjusted, and only a few gratings have been ruled up till now. The maximum area is 120 × 240 mm and spacings are normally 13,900 A (720 grooves/mm), or, when demanded, 6,950 A or multiples. The standard surface is aluminum on chromium on glass.

Dr. Siegbahn's production of gratings is based on the needs of his own institute. He may in the future as before furnish some gratings to other institutes when possible.

Appendix 3. Collaboration and acknowledgements

The origin of this article is a task given to the Section for Optics of the Swedish National Committee of Physics by the International Commission of Optics at its Delft Conference on July 12–17, 1948. A preliminary report was given by the present author on the need of gratings and of manufacturers, according to an earlier task. During the discussion, it was proposed that it would be of advantage to have some common tests and specifications for gratings. All delegates agreed to this opinion, and it was recommended to the Swedish Section to include also this matter in its work.

The Swedish Section[1], in collaboration with Dr. F. A. JENKINS (University of California, at the time in Sweden) has after that worked out these specifications, with the present author as reporter and secretary. The preliminary text was sent out to some leading spectroscopists and to known manufacturers of gratings for their judgment and criticism. In this way, very efficient aid was rendered by answers given from the following persons:

Dr. M. F. HASLER, Applied Research Laboratories, 4336 San Fernando Road, Glendale 4, California, U. S. A.

Dr. H. D. BABCOCK, Mount Wilson and Palomar Observatory, Pasadena, California, U. S. A.

Dr. W. G. LENGTON, Baird Associates, Inc., 33 University Road, Cambridge 38, Massachusetts, U. S. A.

Dr. G. R. HARRISON, Massachusetts Institute of Technology, Cambridge, Massachusetts, U. S. A.

Dr. G. HERZBERG, National Research Council of Canada, Ottawa, Canada.

Dr. P. JACQUINOT, Laboratoire CNRS, Bellevue (S.-et-O.), France.

Dr. J. E. MACK, University of Wisconsin, Madison, Wisconsin, U. S. A.

Dr. A. C. MENZIES, Hilger & Watts Ltd., 98 St. Pancras Way, Camden Road, London, N. W. 1, Great Brit., in collaboration with

Messrs. J. S. CLARK (National Physical Laboratory) and F. TWYMAN, F. R. S. (Hilger & Watts Ltd.)

Dr. D. RICHARDSON, Scientific Bureau, Bausch and Lomb Optical Company, Rochester N. Y., U. S. A.

Dr. M. SIEGBAHN, Nobel Institute of Physics, Stockholm 50, Sweden.

Dr. S. TOLANSKY, Royal Holloway College, University of London, London S. W. 7, Great Brit.

The persons mentioned are of course not responsible for all the contents of the paper, but their opinions and proposals have in most cases been taken up in it. This procedure should guarantee that the specifications will meet the need they are intended for. We state this without denying that there are many special tests and requirements for gratings and several methods are now in development which have not been reported. The Swedish Section wishes to express its gratitude to the persons mentioned and to other colleagues for their effective collaboration in this work.

The Section has, in general, defined its task to summarize what is common and recommendable standard at present and to give information to those who use gratings, rather than to impose any directions on the manufacturers. Though a certain standardization is considered desirable and is recommended, it goes without saying that development should in no way be limited by these rules.

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[1] The members of the Swedish Section for Optics are at present:
Dr. E. HULTHÉN, Dept. of Physics, University of Stockholm, *President.*
Dr. B. EDLÉN, Dept. of Physics, University of Lund.
Dr. Y. ÖHMAN, Observatory of Stockholm, Saltsjöbaden.
Dr. E. INGELSTAM, Dept. of Physics, Royal Institute of Technology, Stockholm 26, *Secretary*

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Uppsala 1950. Almqvist & Wiksells Boktryckeri AB

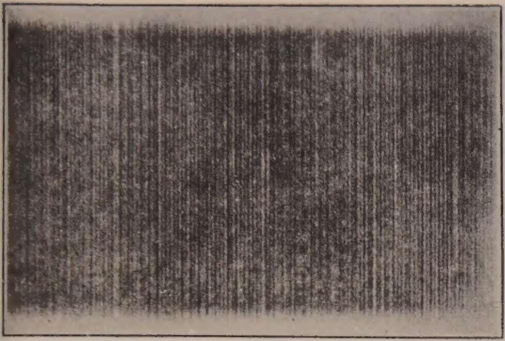


Fig.1. Target pattern from a uniform grating (a single line). The vertical lines are interference fringes which are joined and form the spectral line in focus. Ref.(3)

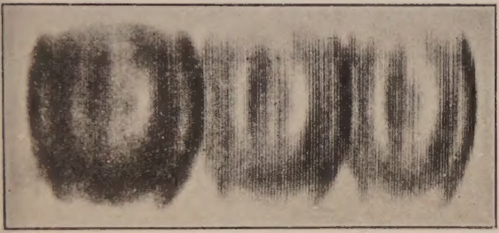


Fig.2. Target pattern from a non-uniform grating (three lines). Ref. (3)

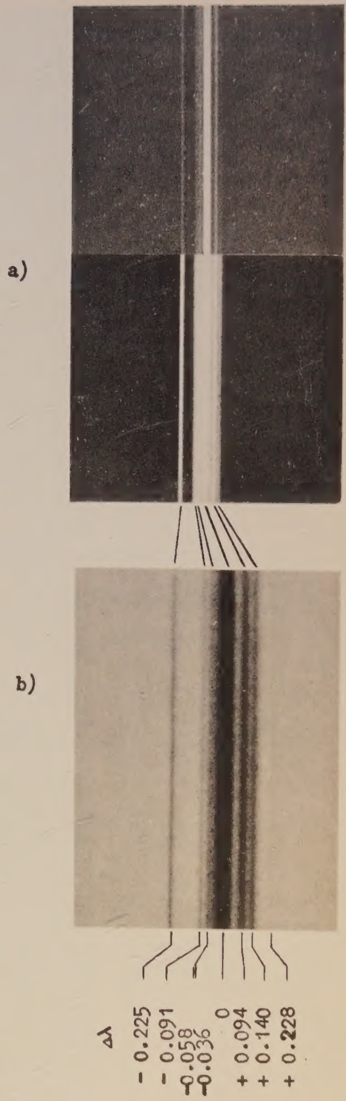


Fig.4. Photographs of the mercury line 5461 A a) at two different times of exposure, b) in another record. Resolving power about 150,000. For Δλ ref. (7)

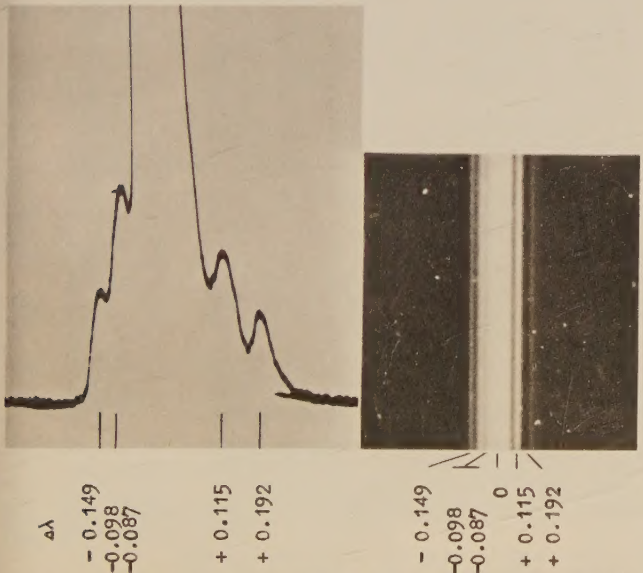


Fig.5. Photomultiplier record and the corresponding photograph of the mercury line 4358 A. Ref.(8). Resolving power about 125,000. For Δλ ref.(7).

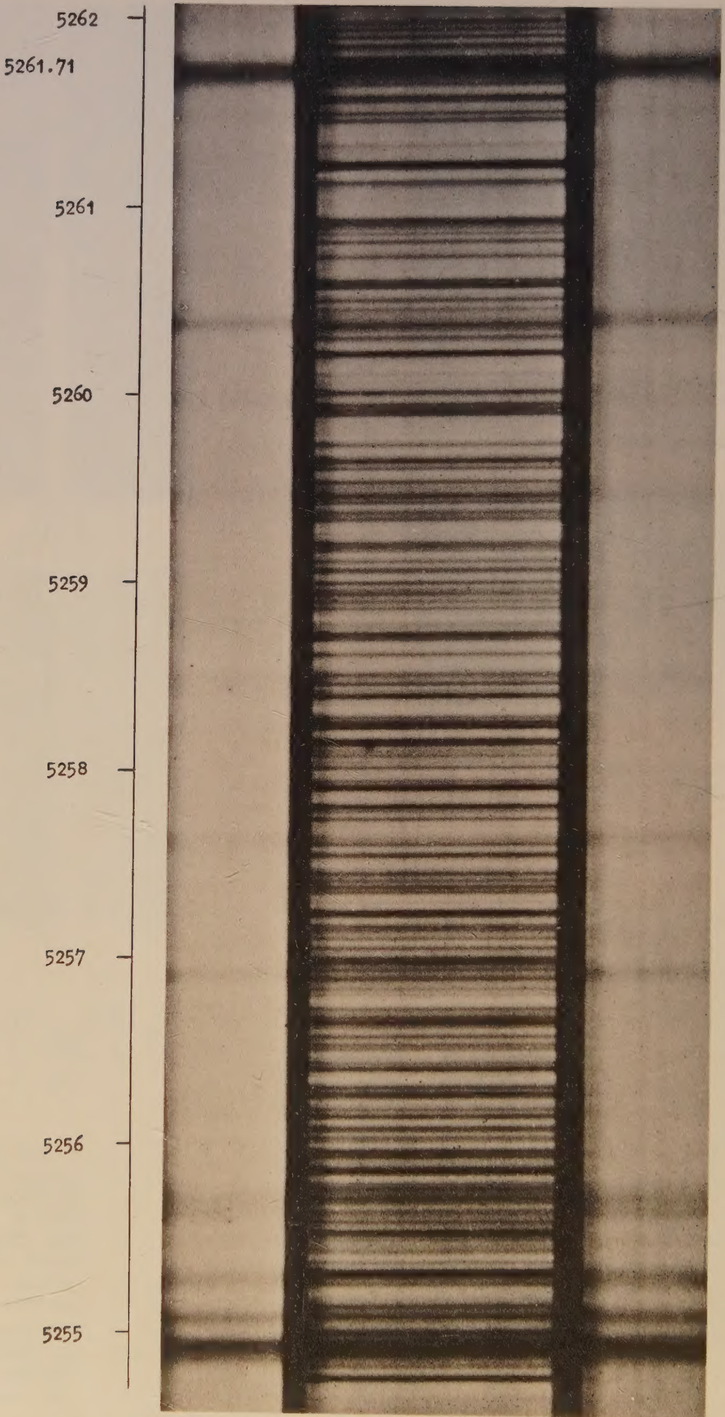
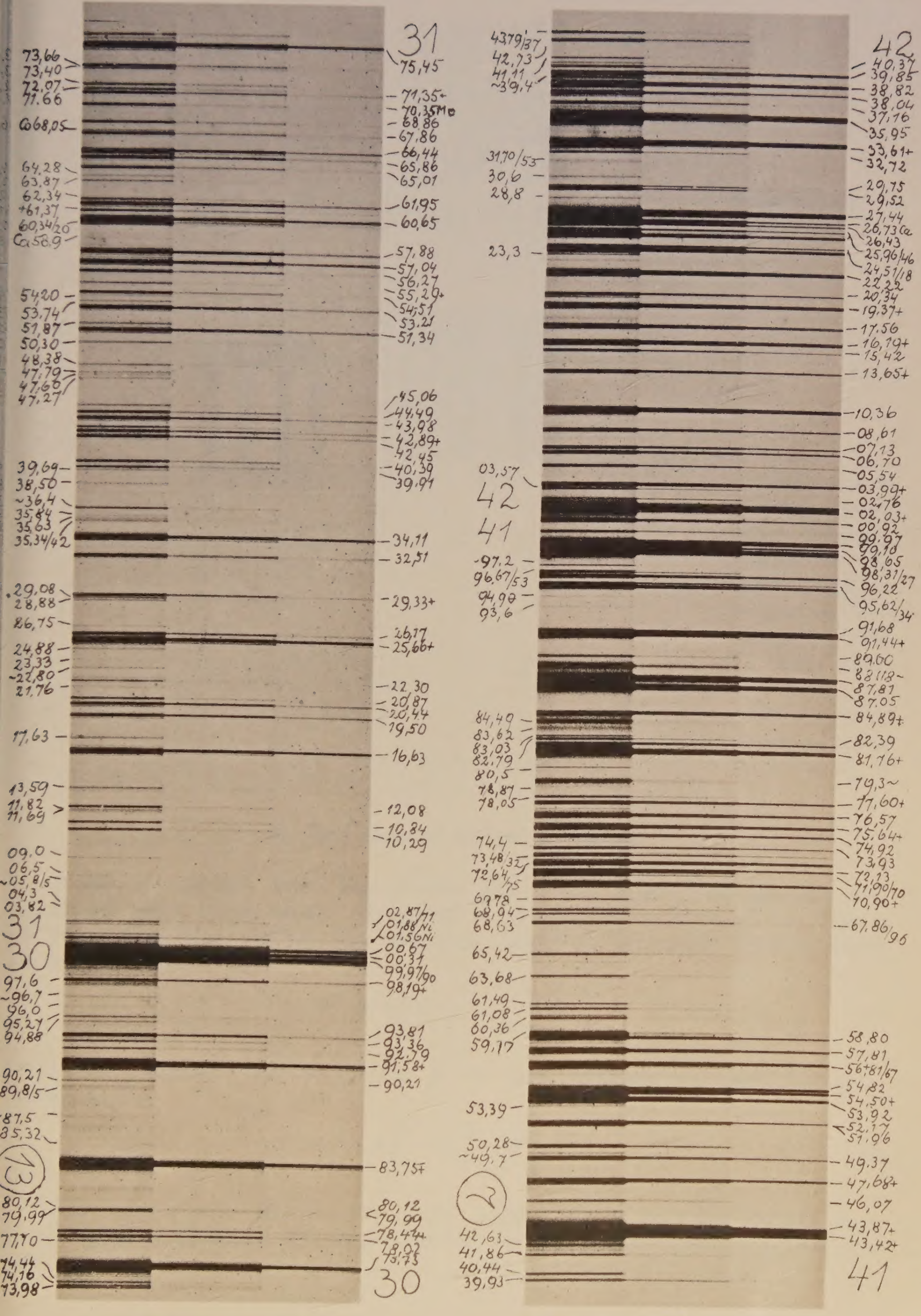


Fig.6. The solar spectrum, 5255 - 5262 A, with the absorption spectrum of iodine vapor (room temperature) superposed on the central strip. Exposure made with the 150 ft Tower telescope on Mount Wilson; Michelson plane grating, 4th order, f = 75 ft. Resolving power about 300,000. Ref.(9).



Wavelengths 3075 - 3175 A

Wavelengths 4143 - 4240 A

Fig. 3. Iron arc spectrum with resolving power of about 30,000. Ref.(4).